EVAS - a practical tool to assess the sustainability of small wastewater treatment systems in low and lower-middle-income countries

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HIGHLIGHTS

- Presents a sustainability assessment tool for small wastewater treatment systems
- Indicators covering five sustainability dimensions provide a holistic approach.
- Uses contextualized sustainability indicators measured by specific targets
- Practically assesses availability of local resources for optimal management.
- Suggests action to raise the sustainability of the wastewater treatment systems.

GRAPHICAL ABSTRACT
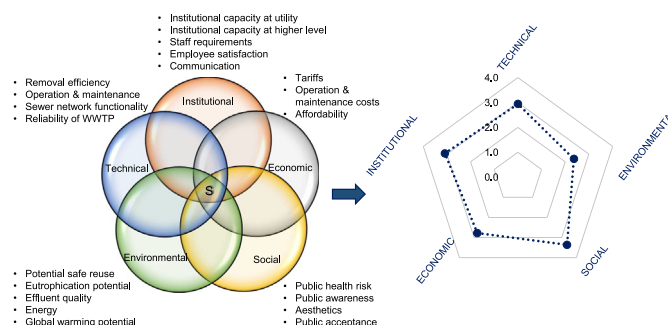
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ABSTRACT

Small wastewater treatment systems (WWTSs) in low and lower-middle income countries still face challenges to achieve optimal performance and acceptable levels of sustainability. Thus, a practical tool, easy to apply by locals, to diagnose the actual status of WWTSs is required in order to identify weak areas for further improvement. This study presents a sustainability assessment tool, EVAS (EVAluación de Sostenibilidad: EVAluation of Sustainability), for small WWTSs in low and lower-middle income countries. The EVAS tool is developed based on a set of contextualized sustainability indicators and sub-indicators in five dimensions (technical, environmental, social, economic, institutional). Each indicator or sub-indicator is broken down into factors, each associated with specific targets to fulfil, and scored using a traffic light scale (0 to 4) indicating unsustainable-low-medium to high levels of sustainability. The tool was developed taking into consideration that local data may sometimes be incomplete and encourages the collection and monitoring of relevant data. The assessment results support local managers or other stakeholders responsible for wastewater management with the identification of weaknesses that need to be addressed. The tool was tested using two case studies involving WWTSs in Bolivia. One WWTS received a medium sustainability rating, whereas the other system received a low sustainability rating, which indicates that several improvements are required in all sustainability dimensions. Stakeholders in the case studies found the tool useful, and suggested ways in which it could be further improved. It is expected that the application of this tool can contribute to raising the sustainability level of small WWTSs in low and lower-middle-income countries.

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1. Introduction

1.1. Background

Rapid urbanization in low and lower-middle income countries, especially in small towns where the existing infrastructure and management capacity are usually limited, accentuates the challenge of providing a fully functioning wastewater treatment service (Caplan and Harvey, 2010; Singh et al., 2015; Sundaravadivel and Vigneswaran, 2003). A small town is defined as a settlement with a mix of urban and rural characteristics (Caplan and Harvey, 2010), which in Bolivia translates into a settlement with a population of 2000–10,000 inhabitants (O'Hare and Rivas, 2007; The World Bank, 2017). The lack of financial resources to operate and maintain small wastewater treatment plants (WWTPs) in low and lower-middle-income countries has been identified as a key reason for the failure of these systems (Brunner et al., 2018; Cossio et al., 2017; Usha Rani and Vasumathi, 2013), alongside inappropriate design or selection of technology (Bdour, 2007; Brissaud, 2007; Mara, 2003; Massoud et al., 2009), poor operation and maintenance (Noyola et al., 2012; Singhirunnusorn and Stenstrom, 2009), lack of technical expertise (Cossio et al., 2019; Noyola et al., 2012; Ujang and Buckley, 2002; Zurita et al., 2012) and lack of monitoring (Cossio et al., 2017; Massoud et al., 2009). According to the United Nations, the achievement of the sustainable development goals (SDGs) is highly dependent on successful management of urban growth, especially in low and lower-middle income countries, which are expected to report the highest growth rate (UN, 2018a). Progress towards achieving Target 6.3 of SDG6 (Clean water and sanitation) is measured using two global indicators: Proportion of wastewater safely treated (6.3.1) and Proportion of bodies of water with good ambient water quality (6.3.2) (UN, 2016; UN, 2018b). Effective and sustainable wastewater treatment in small towns is vital for the successful fulfilment of the criteria set out in these indicators.

The Sustainable Sanitation Alliance (SuSanA) states that a sustainable wastewater management system should be economically viable, socially acceptable, and technically and institutionally appropriate, and it should be designed to safeguard human health, the environment, and natural resources (Andersson et al., 2016). A sustainable small WWTS should meet a broad range of locally and context-dependent needs (e.g. (Benavides et al., 2019; Cossio et al., 2020; Massoud et al., 2009; Nansubuga et al., 2016; Schweitzer and Mihelcic, 2012). Small and decentralized wastewater treatment systems (WWTSs) are also important for effective local recovery of water, sludge and nutrients (Brunner et al., 2018; Massoud et al., 2009), particularly in areas in which water is scarce (Nansubuga et al., 2016), but also as part of a circular economy that is critical to achieving sustainability (Brunner et al., 2018; Molina-Moreno et al., 2017; Molina-Sánchez et al., 2018; Salguero-Puerta et al., 2019; Verbyla et al., 2013). Developing sustainable small WWTSs in low and lower-middle income countries is thus a complex task and accordingly there is a need to support decision-making among local stakeholders when planning and improving the sustainability of these systems (Brunner et al., 2018; Clarkson et al., 2010; Cossio et al., 2020; Dhinadhayalan and Nema, 2012).

Developing a tool to assess sustainability is a challenge (Benavides et al., 2019), as it involves the need to bridge the gap between theoretical concepts and practical measurements (Domínguez et al., 2019; White, 2013). To facilitate the adoption of a holistic approach, such tool should ideally include all the locally relevant aspects the services are required to meet from a sustainability point of view (Sala et al., 2015). Consequently, a tool should typically take into account a variety of different criteria that need to be measured using different units (Molinos-Senante et al., 2014; Villeneuve et al., 2017). Data requirements for a holistic assessment are generally extensive, which in low and lower-middle income countries means further adaptation of such tool as in this context lack of data is common (Benavides et al., 2019).

Almost all tools implicitly or explicitly include weighting of criteria, which is often subjective, sometimes using input from local experts or stakeholders (Ahi et al., 2018; Arroyo and Molinos-Senante, 2018; Molinos-Senante et al., 2014; Muga and Mihelcic, 2008; Singh et al., 2012). If a tool is to be adapted to the local context, it must not only be able to take account of relevant local aspects and encourage the participation of local stakeholders (Hoffmann et al., 2000; Venkatesh et al., 2017), but also encourage decision-makers and policy-makers to put plans or actions into effect at a higher level with the ultimate aim of achieving sustainability (Pope et al., 2004; Pope et al., 2017).

There are several tools that have been developed to support decisions regarding wastewater, each with a specific focus. Examples include the Burden to Capacity Sustainability Assessment (B2C SA) tool for a wastewater treatment infrastructure applied in China (Murray et al., 2009); a Performance Measurement System applied in Italy for improving the efficiency and profitability of larger WWTPs from an internal and managerial perspective (Guerrini et al., 2016); a tool for combining environmental and economic aspects when designing WWTPs for small communities, demonstrated in nine scenarios with different characteristics (Molinos-Senante et al., 2012); a target plot with 13 indicators to evaluate the sustainability of decentralized domestic wastewater treatment technologies (Mena-Ulecia and Hernández-Hernández, 2015); and the decision support tool FitWater, developed to support fit-for-purpose wastewater treatment trains by assessing different ways of reusing wastewater (Chhipi-Shrestha et al., 2017). In Latin America, Benavides et al. (2019) developed a comprehensive and regionally relevant sustainability assessment framework where sustainability was measured by adopting a distance-to-target approach using the traffic light method.

In general, the existing sustainability assessment tools examine specific dimensions, e.g. assessing the economic dimension in relation to the technical or environmental dimensions, using extensive data as well as methods that are generally applied by experts. However, there is often a gap between expert studies on sustainability and practical recommendations that local operators and decision-makers can implement. Development of a tool that uses local data regarding actual performance of the WWTS in operation, current management practices and other aspects relevant to the context of low and lower-middle income countries, including technical, environmental, economic, social and institutional aspects, and can be easily applied by practitioners is expected to overcome this gap.

1.2. Objectives of the study

The overall aim of this study was to develop a sustainability assessment tool to support the decision-making process at existing small WWTSs in low and lower-middle-income countries by increasing the capability and knowledge of WWTS managers, enabling them to take action or plan for long-term improvements in an effort to enhance overall performance and sustainability. In light of the problems typically experienced at small WWTSs, an important aspect was to develop a tool that is possible to use despite that some input data may be missing, and which can support managers and stakeholders to collect relevant data from a sustainability perspective. The specific objectives of this paper are i) to develop a sustainability assessment tool for small WWTSs in low and lower-middle-income countries, and ii) to test the sustainability assessment tool in practice using two case study sites in order to verify the practicality and utility of the tool.

2. Method

The assessment tool, named EVAS (EVAluación de Sostenibilidad: EVAluation of Sustainability), presented in this study is designed to help managers of small WWTSs improve the operational status and sustainability of their systems. The tool is designed to assess systems already in operation. Development and initial testing of the tool are
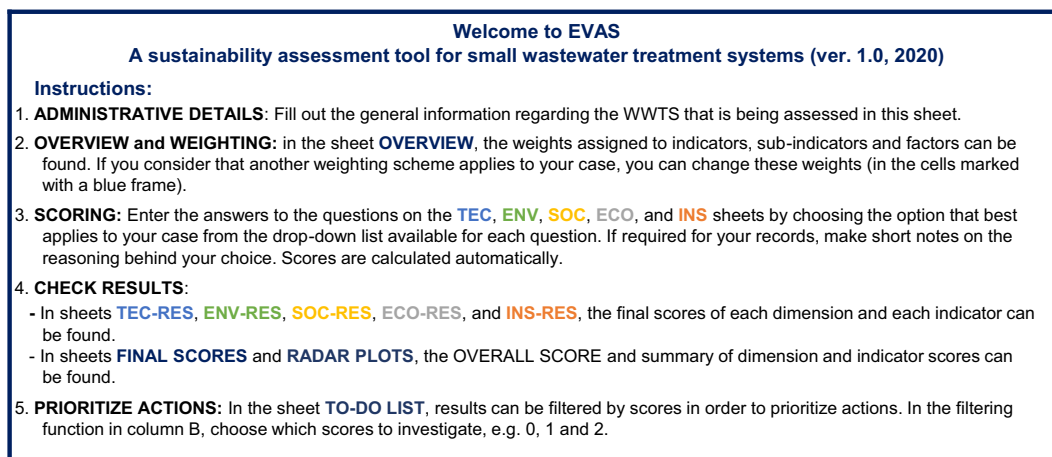
Welcome to EVAS
A sustainability assessment tool for small wastewater treatment systems (ver. 1.0, 2020)

Instructions:

1. **ADMINISTRATIVE DETAILS**: Fill out the general information regarding the WWTS that is being assessed in this sheet.

2. **OVERVIEW and WEIGHTING**: in the sheet **OVERVIEW**, the weights assigned to indicators, sub-indicators and factors can be found. If you consider that another weighting scheme applies to your case, you can change these weights (in the cells marked with a blue frame).

3. **SCORING**: Enter the answers to the questions on the **TEC**, **ENV**, **SOC**, **ECO**, and **INS** sheets by choosing the option that best applies to your case from the drop-down list available for each question. If required for your records, make short notes on the reasoning behind your choice. Scores are calculated automatically.

4. **CHECK RESULTS**:
   - In sheets **TEC-RES**, **ENV-RES**, **SOC-RES**, **ECO-RES**, and **INS-RES**, the final scores of each dimension and each indicator can be found.
   - In sheets **FINAL SCORES** and **RADAR PLOTS**, the OVERALL SCORE and summary of dimension and indicator scores can be found.

5. **PRIORITIZE ACTIONS:** In the sheet **TO-DO LIST**, results can be filtered by scores in order to prioritize actions. In the filtering function in column B, choose which scores to investigate, e.g. 0, 1 and 2.

Fig. 1. Brief instructions to the user of the sustainability assessment tool EVAS, as presented on the first sheet of the Excel tool.

described in Sections 2.1 and 2.2. The interface is in Excel, and an overview of the components that make up the tool is presented in Fig. 1. The tool is available at https://research.chalmers.se/en/publication/516714.

2.1. Development of the suggested sustainability assessment tool

Development of the sustainability assessment tool was based on five sustainability dimensions (technical, environmental, social, economic, institutional) and 21 sustainability indicators. The 21 sustainability indicators applied in the tool were extracted from a list of 27 indicators – identified in a previous study – for small WWTPs in low and lower-middle-income countries (Cossio et al., 2020). During the development of this tool, the original list of 27 indicators was revised to minimize overlapping indicators and focus on indicators relevant to the operational phase. The changes made in the original list of 27 indicators are listed below. Sub-indicators were added to the 21 indicators as necessary in order to specify particular performance aspects or management requirements (Table 1).

- Technical dimension: The original Removal of BOD, TSS, TN, TP and FC[1] indicator was moved from the environmental dimension to the technical dimension and named Removal efficiency (T1). The indicator Complexity of construction and O&M was only evaluated with regard to Operation and maintenance (T2), as the tool is focused on the operational phase and not on choice of technology.

- Environmental dimension: Potential recycling was specifically interpreted as Potential safe reuse (E1) to highlight the need to avoid unacceptable human health risks due to microbial contamination (Cossio et al., 2019; Qadir et al., 2010). The indicator for Quality of effluent and sludge was split: the quality of sludge and water in terms of FC and Helminth eggs was included under Potential safe reuse (E1), and water quality in terms of BOD and TSS was included under Effluent quality (E3). Water quality in terms of TN and TP was included under the indicator Eutrophication potential (E2). The indicator Land area was excluded as it is most relevant in the planning phase.

- Social dimension: Several indicators originally listed as social indicators were moved to the institutional dimension, including Employee satisfaction, Participation, Expertise, and Staff requirements. See further notes under institutional dimension.

- Economic dimension: The indicator Cost effectiveness was merged with Operation and maintenance costs (EC2) and the Investment costs indicator was excluded as it is more relevant in the planning phase.

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[1] BOD – Biological Oxygen Demand, TSS – Total Suspended Solids, TN – Total Nitrogen, TP – Total Phosphorous, FC – Faecal Coliforms.

- Institutional dimension: The originally suggested indicators Expertise and Staff requirements from the social dimension were merged into a single indicator, designated Staff requirements (I3), and Participation from the social dimension was merged with the indicators Information and Interactions into a single indicator Communication (I5) in order to minimize overlap with Public awareness (S2) and Public acceptance (S4) in the social dimension.

There is a slight overlapping of the technical indicator of Removal efficiency (BOD, TSS, TN, TP and FC) with the environmental indicators Potential safe reuse (FC and Helminth eggs), Eutrophication potential (TN, TP), and Effluent quality (BOD, TSS). However, these indicators focus on different aspects – the technology and how well it works on one hand, and whether the effluent complies with safe reuse standards and discharge limits on the other hand.

To assess whether indicators are being fulfilled, a number of factors and corresponding assessment questions were identified for each indicator. For example, factors affecting the indicator Removal efficiency (T1) are Monitoring of removal efficiency (T1-I), Actual removal efficiency (T1-II), and Existence of a long-term plan for improving low performance (T1-III). Another example is the indicator Institutional capacity of the utility (I1), which includes four factors: Roles and responsibilities (I1-I), Procedures (I1-II), Goals of the organization (I1-III), and Long-term goals (I1-IV). Each factor has a multiple-choice assessment question and the answers are scored according to a simplified scale (Table 2), using the logic employed in the traffic light method (Benavides et al., 2019). The details of all 64 factors, how the questions are asked, and the predefined scoring scales for the answers are presented in Supplementary Material 1.

A normalised weighted score is calculated for each sub-indicator, indicator, and dimension, and for the system as a whole. The tool reports the results for factors, sub-indicators and indicators, with only one significant number, whereas the results for dimensions and the overall score are presented with one decimal number. All results are scored according to the ranges detailed in Table 2. The tool allows users to change weightings for dimensions, indicators, sub-indicators, and factors if required, although it is pre-set with a standardized weighting system with a weighting of 1 for all, except the factors that can directly affect measured performance at the WWTS (i.e. removal efficiency, coverage of the sewer network, design of the sewer network, hydraulic loading to the sewer network, design of the WWTP, hydraulic loading to the WWTP, meeting safe reuse limits, eutrophication potential, discharge limits, exposure to public health risks and nuisance level), where the weighting is pre-set at 2. All equations for the calculations of weights and weighted scores are specified in Appendix A. An overview of all sustainability dimensions, indicators, sub-indicators, and factors, as well as

Table 1
List of the indicators included in the tool, sorted under each dimension, together with the objective of each indicator and the corresponding sub-indicators.

Indicators	Objective	Sub-indicators
Technical dimension		
T1. Removal efficiency	High removal efficiency	BOD, TSS, TN, TP, FC
T2. Operation and maintenance	Effective operation and optimal performance of the WWTP	Pre-treatment, Primary treatment, Secondary treatment, Tertiary treatment, Disinfection
T3. Sewer network functionality	Optimal functionality of the sewer network to reduce negative impact at the WWTP	–
T4. Reliability of the WWTP	Resilient treatment processes	–
Environmental dimension		
E1. Potential safe reuse	Safe reuse of water and sludge	Water, Sludge
E2. Eutrophication potential	Low release of nutrients into the receiving water	TN, TP
E3. Effluent quality	Meet the target levels for BOD and TSS in the effluent	BOD, TSS
E4. Energy	Low non-renewable energy consumption at the WWTP	–
E5. Global warming potential	Low greenhouse gas emissions from the WWTP	–
Social dimension		
S1. Public health risk	Low public health risk resulting from discharge of poorly treated or untreated wastewater from the WWTP or the collection system	–
S2. Public awareness	High level of public awareness of ecological and public health risks	–
S3. Aesthetics	Low nuisance level at the WWTP in terms of smell, noise, and visual impact	Smell, Noise, Visual impact
S4. Public acceptance	High level of public acceptance of the location of the WWTP and reuse practice for water and sludge from the WWTP	–
Economic dimension		
EC1. Tariffs	Transparent and documented tariffs	–
EC2. Operation and maintenance costs	A financial structure in which O&M and long-term investment in the WWTP and sewer network are covered	–
EC3. Affordability	Affordable tariffs	–
Institutional dimension		
I1. Institutional capacity (utility)	High capacity within the organization managing the WWTP utility	–
I2. Institutional capacity (higher level)	Clear roles and support at the WWTP from higher level institutions: municipal, regional and national	Municipal, Regional, National
I3. Staff requirements	Staff is available and competent	Operator, Engineer, Communicator, Accountant, Manager
I4. Employee satisfaction	The work environment is good and the salaries satisfactory	–
I5. Communication	Customers receive valuable information about the use and performance of the sewer network and WWTP	–

their respective standard weighting, is presented in Table B1, Appendix B. The tool aims to assess the current status of the WWTS and how far it is from an "ideal" situation, i.e. to measure the distance-to-target. Consequently, all defined scoring scales are global (Monat, 2009) with scores ranging from 0 to 4 (with 4 as the best). Achieving the maximum score also means achieving the defined target.

2.2. Application of the sustainability assessment tool

The sustainability assessment tool was tested in two case studies involving small WWTSs located in Cochabamba, Bolivia. The testing was carried out by a local assessor and a researcher jointly entering data into the sustainability assessment tool, i.e. the assessor provided the input data and the researcher guided the process. The researcher also noted the comments provided by the assessor regarding the relevance of the questions, difficulty answering them, and discussions regarding potential to improve data collection or to modify the questions in the tool.

2.2.1. Case study 1

The first wastewater treatment system (WWTS-1) is located in a small town in the Cochabamba Valley and provides services to 7980 population equivalents. WWTS-1 includes pre-treatment, a storage tank, a mechanical screen, and five treatment trains in parallel. Each

Table 2
Overview of the traffic light scoring system used in the EVAS tool and an example of how a factor is scored in relation to the corresponding multiple-choice questions and answers.

Colour	Score	Explanation of the assessment result	Example: Quality of effluent, Discharge limits (E3a,b-II)
			When monitoring, do the results comply with the limits for safe discharge?
Grey	0	**NOT POSSIBLE TO ASSESS** It is not possible to assess the level of sustainability due to a lack of information.	No information
Red	1	**UNSUSTAINABLE** The requirement is not fulfilled.	No
Yellow	2	**LOW SUSTAINABILITY** The requirement is partly fulfilled.	Partly, in ≥ 50% of the observations
Light green	3	**MEDIUM SUSTAINABILITY** The requirement is fulfilled relatively well.	Yes, in ≥ 70% of the observations
Dark green	4	**HIGH SUSTAINABILITY** The requirement is fulfilled.	Yes, always

Integrated scores are classified according to the following ranges: score 0 = 0; score 1: >0 and <1.5; score 2: ≥1.5 and <2.5; score 3: ≥2.5 and <3.5; score 4: ≥3.5.

treatment train has a grease chamber, an upflow anaerobic sludge blanket (UASB) reactor, two biofilters in parallel, and a sludge drying bed. In total, the WWTP has five grease chambers, five UASB reactors, and 10 biofilters to treat the wastewater. The construction of the WWTS-1 was funded through a combination of external support, municipal funding, and user contributions. The municipality is responsible for the financial management of the WWTS-1. The operation and maintenance of the sewer network and the WWTP is carried out by the foundation, which was also responsible for constructing the WWTP at the request of the municipality. The staff responsible for the management of WWTS-1 (WWTP and sewer network) include a full-time operator as well as a manager, engineer, communicator, and accountant, all of whom work part-time. The assessor in this case was the manager, who provided all the input data for the assessment and contributed to the testing of the tool.

2.2.2. Case study 2

The second wastewater treatment system (WWTS-2) is located in another small town in the Cochabamba Valley and provides services to 3344 population equivalents. The treatment processes include pretreatment, a UASB reactor, two biofilters, a maturation pond, and a sludge drying bed. The treatment plant was funded by the national government. Once construction was completed, responsibility for the WWTS-2 was transferred to the local water association. The water association was already responsible for the drinking water services before taking on responsibility for the management of the sewer network and wastewater treatment. For this case study, the tool was tested and validated using monitoring data and information collected in a previous study (Cossio et al., 2019). The assessment in this case was made by two local researchers (Cossio and Mercado) with the support of an undergraduate student who at the time was carrying out fieldwork at the WWTP.

2.3. Sensitivity analysis

A simplified sensitivity analysis was carried out for the case study assessments to investigate the effects of applying different weights to indicators and dimensions using scenario analysis. Three scenarios were investigated: i) all weights in the tool being equal to 1 (see Appendix B), ii) a ranking of sustainability dimensions according to technical and social experts from the study by Cossio et al. (2020) where the institutional dimension was given a weight of 3, the social, economic and technical dimensions were each given a weight of 2 and the environmental dimension was given a weight of 1, and iii) each of the 21 sustainability indicators was weighted equal (4.76% each), thus compensating for the

hierarchical structure which results in lower weights for indicators in dimensions with more indicators than for indicators in dimensions with fewer indicators.

3. Results

3.1. Sustainability assessment of case study 1

The overall results obtained from the sustainability assessment of WWTS-1 are summarized in Table 3. The sustainability assessment of WWTS-1 resulted in an overall sustainability score of 2.9, i.e. medium sustainability level. At the indicator level, most indicators (11 out of 21) received a score of 3. Five indicators in the assessment received a high sustainability score (4): Reliability of the WWTP, Potential safe reuse, Public acceptance, Institutional capacity at the utility, and Employee satisfaction. Only five indicators received low scores (1 or 2) at the indicator level. The indicators Sewer network functionality, Affordability, and Institutional capacity on a higher level received a score of 2, whereas Energy and Global warming potential received a score of 1.

Each indicator score is a weighted sum of the individual scores under each sub-indicator and factor (equations in Appendix A), and Fig. 2 presents the percentages of the individual scores under each dimension. There are some low scores in each dimension, although the social dimension stands out in the assessment with no red scores and only 7% yellow scores.

Details of all low scores (0, 1 and 2) in each dimension in the assessment are presented in Appendix C, Table C1. This table can be viewed as a summarized to-do list that could support the identification and prioritization of actions. For example, the indicator T3 Sewer network functionality scored 1 for factor T3-II Design and factor T3-IV Hydraulic loading, which are on top of the to-do list as their factor weightings are 2; and factor T3-III Breakdown, factor T3-V Clogging and factor T3-VI Long-term plan SEW are next on the to-do list as their factor weightings are 1. In other words, a prioritized activity in Case study 1 regarding indicator T3 Sewer network functionality would be to implement a long-term plan to improve the design of the sewer network to ensure better management of failures due to breakdown, clogging and hydraulic loading. The detailed results of the assessment of Case study 1 are presented in a locked version of the tool itself – in an Excel file – as Supplementary material 2. In the following sections all the results are presented according to each dimension.

3.1.1. Technical dimension

The indicator scores for Removal efficiency (T1) and Operation and maintenance (T2) are 3, indicating that in general the WWTP monitors

Table 3
Summary of the EVAS assessment results for Case study 1.

Case study 1 – Overall sustainability score: 2.9									
Technical dimension	**2.9**	**Environmental dimension**	**2.4**	**Social dimension**	**3.4**	**Economic dimension**	**2.8**	**Institutional dimension**	**3.1**
T1. Removal efficiency	3	E1. Potential safe reuse	4	S1. Public health risk	3	EC1. Tariffs	3	I1. Institutional capacity (utility)	4
T2. Operation & maintenance	3	E2. Eutrophication potential	3	S2. Public awareness	3	EC2. Operation & maintenance costs	3	I2. Institutional capacity (higher level)	2
T3. Sewer network functionality	2	E3. Effluent quality	3	S3. Aesthetics	3	EC3. Affordability	2	I3. Staff requirements	3
T4. Reliability	4	E4. Energy	1	S4. Public acceptance	4			I4. Employee satisfaction	4
		E5. Global warming potential	1					I5. Communication	3

1/red = requirement not fulfilled, 2/yellow = requirement partly fulfilled, 3/light green = requirement fulfilled relatively well, 4/dark green = requirement fulfilled.
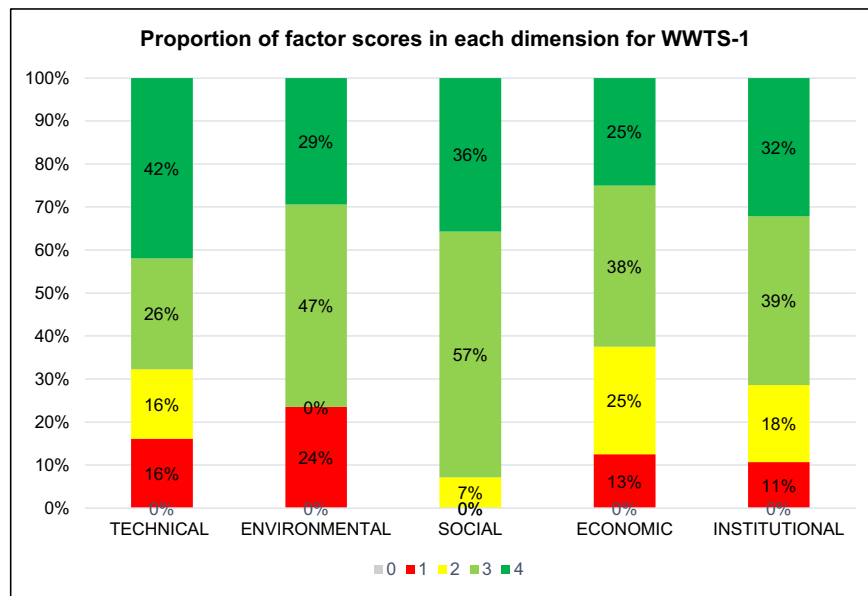
Fig. 2. Proportion of factor scores in each dimension for WWTS-1, expressed as percentages.

and meets effluent requirements most of the time and that most of the treatment unit processes at the WWTP are working well. Removal efficiency for TSS and FC received a score of 2, as well as Long-term maintenance of all treatment units (pre-treatment, UASB reactor and Biofilter). As mentioned in the example in the previous section, Sewer network functionality (T3) received a low score (2) in this case study. However, Coverage of the sewer network (T3-I) is satisfactory and received the highest score (4). Reliability of the WWTP (T4) received a score of 4 for all factors included in the indicator. Actions directed at improving the sewer network should thus be prioritized in the technical dimension, as well as following up the low removal rates of TSS and FC and improving the long-term maintenance of the treatment units at the WWTP.

3.1.2. Environmental dimension

The reuse of both treated wastewater and sludge is practised and for the indicator Potential safe reuse (E1), the lowest factor score (1) was due to a lack of regular monitoring of the sludge (E1b-II). However, all monitoring samples that were collected and analysed for water (once every three months) and sludge (once a year) complied with safe reuse limits in relation to the type of crops that were being irrigated (in this case corn). As regards eutrophication potential, the sub-indicators TN and TP scored 3 for Monitoring -Eutrophication Potential (E2-I) and Compliance with discharge limits to avoid eutrophication (E2-II). All sub-indicators and factors under the indicator Effluent quality (E3) relating to BOD and TSS received scores of 3 and 4. The WWTP always complies with the limits for BOD removal (E3a-II), but only in 70% or more of the samples for TSS removal (E3b-II). The frequency of Monitoring-Effluent quality (E3-I) and compliance with limits for TSS (E3b-II) could be further improved to obtain the maximum score of 4 for both factors. The lowest score (1) in the environmental dimension was received for Energy (E4) and Global warming potential (E5), and it is clear that energy saving, use of renewable energy sources, and reducing emissions have not yet been prioritized in this system.

3.1.3. Social dimension

In general, the assessment of the social dimension resulted in high scores. All but one scored either 3 or 4, which means that wastewater treatment practice is accepted locally. The only low score (2) was related to Claims (S1-II), i.e. there are claims from the public at least once a year related to people or animals being affected negatively by

discharges from the WWTP. This is linked to the quality of the effluent discharged and it is probable that improvements in the technical performance will reduce the number of claims. In the social dimension, the level of Public awareness (S2) of the benefits of the WWTP could be increased and action should be taken at the WWTP to reduce the smell (S3a-II). Despite occasion public claims and odour problems, the high score of 4 for the Public acceptance (S4) indicator confirms that the local population values the benefits the WWTP brings to the town, specially to farmers that reuse the effluent.

3.1.4. Economic dimension

The assessment of the Tariffs (EC1) indicator showed a very good Tariff structure (EC1-I, score 4) and very good Documentation of financial management with monthly and annual financial reports available for customers (EC1-II, score 4). However, Follow-up (EC1-III) to ensure the tariff structure is correct over time requires improvement (score 1). As regards Operation & maintenance costs (EC2), the economic requirements for Optimal operation and maintenance (EC2-I) and Long-term investment (EC2-II) received scores of 3. Affordability (EC3) scored 3, indicating that a large proportion of the customers pay their tariffs on time (EC3-I), but scored 2 for factor EC3-II, in turn indicating that the payment capacity of customers is not very well known and the municipality does not have very effective strategies in place to raise the affordability level among customers (EC3-III). Efforts to acquire a better understanding of the true affordability level should be implemented.

3.1.5. Institutional dimension

The indicator Institutional capacity (I1) at the utility level scored the highest (4) in all the factors included in the assessment. The foundation in charge of the management of the WWTS has experience in implementing and managing other WWTPs in the study area. The indicator Institutional capacity at a higher level (I2) scored 2, meaning that better-structured support is required from the institutions at higher levels. Although the roles of the municipal technical services department and the Ministry of Environment and Water are well-defined (I2a-I and I2c—I), the actual level of fulfilment of their duties is low. External support from the municipality (I2a-II) is low (2) and support from the Ministry (I2c-II) is very low (1). At the Regional level (I2b), roles and duties are neither well-defined nor fulfilled, both scoring 1. As regards Staff requirements (I3), an operator and an engineer with adequate skills scored 4 and 3, and they are generally available and receive

regular training (score 4). A communicator, accountant, and manager are available part-time, and although their level of expertise meets the requirements (score 3), they do not receive regular training, and consequently the maximum score of 4 could not be obtained. The manager indicated that due to the size of the WWTP it is not financially viable to have all the staff employed full-time. As they also manage other WWTPs, staff salaries are covered by more than one WWTP. As regards the Employee satisfaction (I4) indicator, the score for working conditions was 3 due to a lack of documentation of safety procedures, although it scored 4 for salary level. As regards the Communication (I5) indicator, communication by managers to customers about Use of the sewer network (I5—I) scored the maximum of 4. However, for information regarding the performance of the WWTP (I5-II), it received a score of 2 as the information is not distributed to customers. Although the staff inform users when there is a risk of exposure (I5-III) due to a discharge of poorly treated wastewater, no standard procedure has been introduced and consequently the score was 3.

3.2. Sustainability assessment of case study 2

The results obtained from the sustainability assessment of WWTS-2 are summarized in Table 4. The sustainability assessment of WWTS-2 resulted in an overall sustainability score of 1.6, i.e. a Low level of sustainability. On the indicator level, almost half of the indicators (9 out of 21) received a score of 1, resulting in at least one unsustainable indicator in each dimension. Ten indicators in the assessment scored 2 and only two indicators received a score of 3 (the technical indicator T4 - Reliability and the social indicator S3 - Aesthetics). No indicator received the highest score (4) in the assessment.

The assessment resulted in a majority with scores of 1 and 2, with only the technical dimension and social dimension receiving a low proportion of 4 scores (Fig. 3). The economic and institutional dimensions have the highest proportion of indicators that scored 3: 33% and 20%, respectively. From Fig. 3, it can also be seen that there are three factors that could not be assessed due to a lack of information, as indicated by the 0 score in the environmental and economic dimensions (i.e. Compliance with reuse limits for sludge (E1b-III), Payment capacity (EC3-II) and Strategy for Affordability (EC3-III)). Detailed results of all low scores (0, 1 and 2) in each dimension in the assessment are presented in Appendix C, Table C2. Supplementary material 3 presents the detailed results of the assessment of Case study 2 in a locked version of the EVAS tool as an Excel file. In the following sections, the results of Case study 2 are summarized according to dimension.

3.2.1. Technical dimension

The Removal efficiency indicator (T1) is assessed to be unsustainable. The factor Monitoring for removal efficiency (T1-I) scored 1 for all sub-indicators (BOD, TSS, TN, TP, FC), corresponding to a monitoring frequency of once a year. The actual Removal efficiency (T1-II) is <50% (score 1) for all, while for TSS the removal efficiency is between ≥80% and <95% (score 3). A Long-term plan (T1-III) to improve the situation for all sub-indicators that scored 1 for Removal efficiency is only partially in place. As regards Operation and Maintenance (T2), the situation is almost as unsustainable with a score of 2. There are no O&M manuals (T2-I) for any of the treatment levels, i.e. pre-treatment, and primary, secondary, and tertiary treatment (score 1), and although Short-term O&M (T2-II) is performed in part (score 2), Long-term maintenance is lacking for all treatment steps (score 1) except for pre-treatment (T2a-III: score 2). As regards Sewer network functionality (T3), scores of 1 were given to the factors Design (T3-II), Hydraulic loading (T3-IV), Clogging (T3-V), and Long-term plan for the sewer network (T3-VI). Coverage (T3-I) scored 2 as the coverage of the sewer network is between ≥50% and <75%, but since Breakdowns due to material failure in the network (T3-III) are rare, it scored 4. As regards the Reliability of the WWTP (T4), the Design of the WWTP (T4-I) only includes a bypass and due to the relatively high frequency (once a month) of Hydraulic loading (T4-III) reaching the WWTP, both these factors scored 2. The remainder of the factors under this indicator scored 4.

3.2.2. Environmental dimension

In the environmental dimension, the assessment of the indicator Potential safe reuse (E1) showed that water is sometimes reused (E1a-I), resulting in a score of 2, and that sludge is always reused (E1b-I) resulting in a score of 3. However, there is no Monitoring for a safe reuse (E1-II) of either water or sludge for reuse (score 1), the Safe reuse limits (E1-III) are not being complied with for water (score 1), and no information is available regarding sludge (score 0). Furthermore, there is no Long-term plan (E1-IV) for meeting safe reuse limits (score 1). The Eutrophication potential (E2) scored 1 for both sub-indicators (TN and TP) in all the factors: Monitoring for eutrophication potential (E2-I), Eutrophication potential (E2-II), and Long-term plan to reduce eutrophication potential (E2-III). Effluent quality (E3) received a score of 1 for Monitoring (E3-I) and Compliance with Discharge limits (E3-II) for BOD (E3a-II), but 2 for TSS (E3b-II). In the case of TSS and BOD, Long-term plans (E3-III) to improve the quality of the effluent are only partly in place, hence the score of 2. Similar to Case study 1, the environmental indicators Energy (E4) and Global warming potential (E5) only received a score of 1.

Table 4
Summary of the EVAS assessment results for Case study 2. The scores are calculated according to the equations presented in Appendix A.

Case study 2 – Overall sustainability score: 1.6									
Technical dimension	**1.8**	**Environmental dimension**	**1.1**	**Social dimension**	**1.7**	**Economic dimension**	**1.7**	**Institutional dimension**	**1.7**
T1. Removal efficiency	1	E1. Potential safe reuse	1	S1. Public health risk	1	EC1. Tariffs	2	I1. Institutional capacity (utility)	2
T2. Operation & maintenance	2	E2. Eutrophication potential	1	S2. Public awareness	2	EC2. Operation & maintenance costs	2	I2. Institutional capacity (higher level)	2
T3. Sewer network functionality	2	E3. Effluent quality	2	S3. Aesthetics	3	EC3. Affordability	1	I3. Staff requirements	2
T4. Reliability	3	E4. Energy	1	S4. Public acceptance	1			I4. Employee satisfaction	2
		E5. Global warming potential	1					I5. Communication	1

1/red = requirement not fulfilled, 2/yellow = requirement partly fulfilled, 3/light green = requirement fulfilled relatively well, 4/dark green = requirement fulfilled.
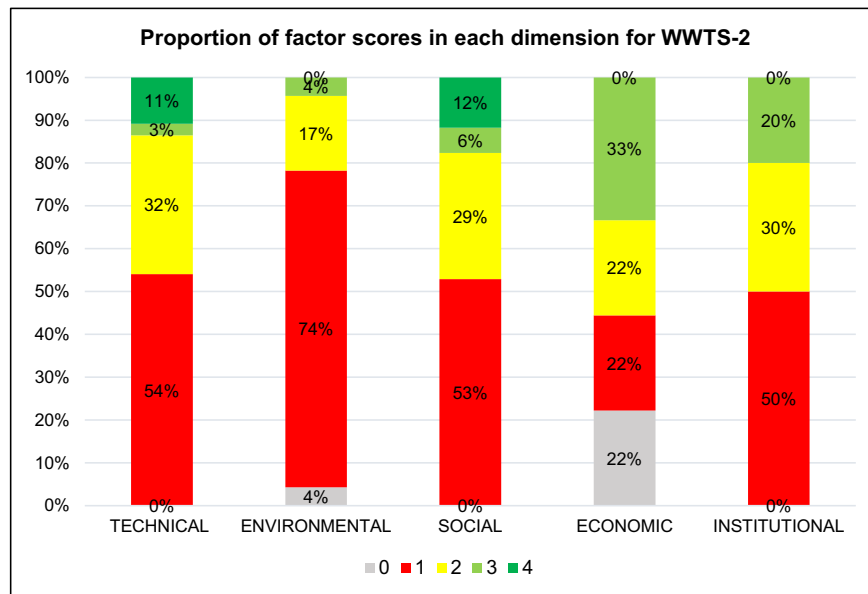
Fig. 3. Proportion of factor scores in each dimension for WWTS-2, expressed as percentages.

3.2.3. Social dimension

The problems experienced in the technical and environmental dimensions regarding the discharge of poorly treated wastewater are also reflected in the Public health (S1) indicator, where all the factors scored 1, i.e. Exposure (S1-I), Claims (S1-II), and Long-term plan to protect public health (S1-III). The quality of the effluent needs to be improved to ensure public health is safeguarded. The Level of public awareness (S2) for Public health concerns (S2-II) scored 3, i.e. the users acknowledge the importance of the WWTP in safeguarding public health. However, as public awareness in relation to Ecological concerns (S2-I) and proper Use of services (S2-III) was low, and there is no Long-term plan to raise Public awareness (S2-IV), they all scored 1. As regards the indicator Aesthetics (S3), only Smell was identified as an issue with regard to Nuisance level (S3a-II), scoring 2, but there was no nuisance with regard to Noise (S3b-II) or Visual impact (S3c-II), each scoring 4. There was no long-term plan for reducing smell (S3a-III). Public acceptance (S4) of the WWTP is also quite low. The public is opposed to Reuse practice for water and sludge from the WWTP (S4-II: score 1), and partly opposed to the Location of the WWTP (S4-I: score 2). There is no Long-term plan to increase Public acceptance (S4-III), resulting in a score of 1.

3.2.4. Economic dimension

For the indicators Tariffs (EC1), Tariff structure (EC1-I), and Documentation on financial management (EC1-II) the score was 3, but 1 for not having a Follow-up system in place to ensure an appropriate tariff over time (EC1-III). The result of the assessment of the Operation and maintenance costs indicator (EC2) clearly shows there is insufficient funding to implement optimal O&M. The Economic requirements, EC2-I factor, i.e. the tariffs collected from users on a monthly basis, do not cover the regular O&M costs, thus scoring 1. In contrast, funding for Long-term investment is partly assured (EC2-II: score 2) and a Long-term plan (EC2-III: score 2) to solve these financial issues is partly in place. Affordability (EC3) was in part good with regard to Payment of tariffs (EC3-I: score 3), as >70% of the customers pay on time. However, as regards Payment capacity of the users (EC3-II) and the existence of a Strategy to make the service affordable for everyone (EC3-III), no information was available for the assessment.

3.2.5. Institutional dimension

In the assessment of the Institutional capacity at the utility level (I1), Roles and responsibilities of the staff (I1-I) were quite clear

(score 3) and certain Procedures were documented (I1-II: score 2) to support the staff. However, there were no clear Goals of the organization (I1-III) or Long-term goals (I1-IV) (score 1). The assessment of the Institutional capacity at higher levels (I2) revealed certain results that were different compared to Case study 1. The key institutions are the same on the regional level and the national level, i.e. the Regional Environmental Authority in Cochabamba and the Bolivian Ministry of Environment and Water, and at the municipal level it is the technical services department in the area in which WWTS-2 is situated. In this case study, the clarity of Roles and responsibilities (I2-I) and External support (I2-II) was very low (score 1), both at the municipal and national level. However, at the regional level, Roles were clear (I2b-I) and External support was good (I2b-II). As the Regional Environmental Authority requested monitoring of the results of the WWTS-2 to check whether the discharge requirements were being fulfilled, both factors scored 3. This is in contrast to WWTS-1, which never received such a request from the Regional Environmental Authority. The Staff requirements (I3) indicator in terms of Availability only scored 3 for Operator (I3a-I). The Level of expertise required was met for the Engineer (I3b-II) and the Accountant (I3d-II) and they were both assigned a score of 3. There was no Long-term plan to improve the situation for any of the staff categories (I3-III: score 1). Employee satisfaction (I4) in terms of Working conditions (I4-I) and Salary level (I4-II) was low (score 2). As regards Communication (I5), customers are informed about proper Use of the sewer network (I5-I) on certain occasions (score 2). However, no open information is provided to the customers regarding Wastewater utility performance (I5-II) and there were no Warnings about exposure risks to customers (I5-III) when there is a discharge of poorly treated or untreated wastewater, and consequently both scored 1. Indicators in the dimensions are interconnected and influence each other, and all dimensions are therefore important if wastewater is to be treated successfully.

3.3. Results of the sensitivity analysis

The results of the sensitivity analysis with two decimal numbers are summarized in Table 5. The different weighting scenarios do not produce a significant difference in outcome of the sustainability assessment compared to the base case.

Table 5

Results of the sensitivity analysis showing the overall sustainability scores of the assessments with two decimal numbers for the base case scenario and the three additional weighting scenarios described in methods. The colours correspond to the explanations in Table 2.

	Base scenario	Scenario 1	Scenario 2	Scenario 3
Case study 1	2.91	2.89	2.98	2.90
Case study 2	1.62	1.64	1.68	1.59

4. Discussion

4.1. Case studies and sensitivity results

The assessment results for Case studies 1 and 2 were quite different in terms of sustainability level. The performance of the system in Case study 1 is quite good although there are still certain issues that need to be addressed, whereas the results for Case study 2 show a WWTS with a low sustainability level and multiple issues that need to be addressed. In Case study 1, it is possible to identify actions that need to be taken in each dimension, but for Case study 2, where low scores are so numerous, it is difficult to prioritize the actions that need to be taken. Many of the issues for Case study 2 are linked to problems in the technical and environmental dimensions, i.e. lack of monitoring of effluents, low removal efficiencies, and non-compliance with discharge or safe reuse limits. The primary function of a WWTP is to protect human health and the environment downstream and both technical and environmental indicators reflects how well the WWTP achieves this. Even if all other dimensions score high and the overall system would get a relatively high integrated score, it is important to also achieve sustainability within each dimension as e.g. the economic aspects included in the tool cannot directly compensate for e.g. negative environmental effects downstream the WWTP. For Case study 2, it is important to communicate the present issues to higher-level institutions and possibly ask for support.

Both cases received a low score (overall 2) for the indicator Sewer network functionality, which is in line with results from the previous indicator study where the sewer network was highlighted as important and an often weak link (Cossio et al., 2020). It is indeed important as any wastewater that does not reach the WWTP will not be treated and any extra water that enters the collection system as a result of infiltration and rainwater inflow will decrease the removal efficiency of the WWTP. In both case studies, the environmental indicators Energy reuse and Global warming potential received very low scores. It is understandable that these types of global environmental targets have lower priorities in the light of the more direct operational problems these types of WWTSs are facing. In the long run however, there is a need to promote awareness of these environmental concerns also in low and lower-middle income countries and identify opportunities for improvement. Also, a town where infrastructure investments are still in the future has unique possibilities to avoid the unsustainable solutions of those who chose their wastewater systems 50 or 100 years ago.

In Case study 2, data was lacking for the assessment of three factors (Compliance of sludge quality with Safe reuse limits, Payment capacity of users, and a Strategy for raising affordability among users), as reported in the to-do list results (see Appendix C, Table C2). In low and lower-middle income countries in general, the lack of proper record-keeping in small WWTSs is a common issue. In the EVAs tool, a score of 0 is assigned to a factor when there is no information available, which will decrease the overall sustainability score. For Case study 2, if all three scores of 0 would be replaced by the highest score of 4, the overall score would change from 1.6 to 1.8, and the economic dimension would shift from 1.7 (yellow) to 2.6 (light green). This would not however, change the overall impression that there are several areas to improve regarding WWTS-2. For Case study 1 on the other hand, if all factors that involves monitoring of chemical data (T1-I Monitoring of removal efficiency; E1-II Monitoring of safe reuse; E2-I Monitoring of

eutrophication potential and; E3-I Monitoring of effluent quality) were scored 0 instead of 3, the overall sustainability score would decrease from 2.9 to 2.4 and would turn yellow instead of light green. In theory, there may thus be systems that work rather well, but still receive an overall low score in the EVAS tool if there is no chemical data available. However, we argue that an important part of a long-term sustainable system is that managers are aware of the actual status of the system by regularly collecting relevant data, and that it is difficult to manage a system optimally in the long run if there is no knowledge of the actual status of the effluent. One of the objectives of the tool is to build up a body of knowledge among managers and stakeholders about the WWTS, and by clearly indicating that there is insufficient data, they can become more aware and motivated to systematically collect data.

The simplified sensitivity analysis used to investigate different weighting schemes indicates that the tool is not very sensitive to non-extreme changes in weights. This is because the tool includes several factors and sub-indicators in the assessment, and thus the overall result is an integrated number not easily affected by quick fixes, such as slightly adjusting weights. Instead, systematic improvements of the WWTS on multiple indicators will have a greater impact on the overall results of the sustainability assessment.

4.2. Potential improvements to the tool

Although the general feedback from the application of the tool in the case studies was very positive, and some improvements were carried out as an immediate result of the testing, potential further improvements to the tool were identified. The application of the tool showed in general that the theoretical description of the indicators could to some degree be misinterpreted by the assessor. In contrast, the scoring based on quantitative data, mainly involving the technical, environmental and economic dimensions, was easier to assess in comparison with the qualitative data, e.g. the social dimension. Constructed scoring scales for the assessment of qualitative data can lead to vagueness and misinterpretation if the linguistic terms used are not well defined (Kamble et al., 2017) and there is a need for further development regarding social indicators and the methods to assess them, in order to reduce this type of subjectivity (Padilla-Rivera et al., 2016; Popovic and Kraslawski, 2018). As the personal judgement of the assessors potentially could influence interpretation and score assessment, a further improvement to the tool would be to provide more detailed descriptions of the factors specified in the tool, especially for those with qualitative character. Further specific comments on indicators in each sustainability dimension, except the social dimension, are discussed below.

4.2.1. Technical dimension

The questions and scores could potentially identify seasonal events for the factors Hydraulic loading and Clogging in the Sewer network functionality indicator (T3). The same applies to the Hydraulic loading factor in the Reliability of the WWTP (T4) indicator, since overflow issues mostly occur during the rainy season. It is important that the EVAS assessment reflects how the system copes with the normal and reoccurring conditions and not only those of the week or month just prior to the assessment. As regards the technical factor Organic loading (T4-IV), a suggestion was to ask whether there are small industrial enterprises and, if so, do they pre-treat their wastewater before discharging it into the sewer network. Municipal authorities could potentially regulate this

type of discharge to avoid overloading the WWTP. The assessor in Case study 1 suggested that the assessment of Renewable Energy in (E4), should take account of the size of the plant in order to create a more accurate scoring scale. The potential energy that can be generated from, e.g. anaerobic digestion, is not significant if the utility is small. This factor could also be expanded on by asking whether the plant primarily opts to source energy from renewable sources instead of simply focusing on whether the plant manages to reuse energy generated within its own operations.

4.2.2. Environmental dimension

For the Potential safe reuse (E1) indicator and the factor Safe reuse limits for water, the question should optimally depend on the type of crops for which the treated wastewater is used (i.e. restricted and non-restricted irrigation). In Case study 1 for example, the farmers use the treated wastewater to irrigate corn, which is a non-restricted irrigation crop, and there are thus no limits for safe reuse. However, if the tool is to be updated with a scoring scale for specific crops, the managers will also need to know what crops are irrigated using wastewater, implying more monitoring and more detailed, up-to-date knowledge of agricultural practices in the surroundings.

For Eutrophication potential (E2), it was suggested that this indicator is only important in those cases where the effluent is being constantly discharged into receiving water bodies and that questions and scores should be adjusted to fit site-specific conditions. In Case study 1, all the effluent is used for irrigation during the dry season and during the rainy season it is discharged into a stream. However, even though this first way of managing the effluent will reduce the eutrophication potential in the receiving water bodies, a site-specific assessment is needed to justify deviations from the set discharge standards. Further, in a previous study it was stated that practising wastewater irrigation could give rise to ecological risks associated with accumulation of nutrients in the soil (Cossio et al., 2019). The results suggested that the reuse of treated wastewater should be managed carefully to avoid eutrophication of water sources as a result of accumulation in the soil.

4.2.3. Economic dimension

The Affordability (EC3) indicator and the Payment capacity factor were regarded as being difficult to score. In Case study 1, for example, the municipality had set the charges for the services before the WWTP was constructed based on a prediction of whether the users could pay the tariffs. In addition, the manager of the WWTS-1 stated that in general the population of small towns that have drinking water and sewer network services can afford the tariffs for these services. Consequently, the question concerning if there was a strategy to handle users who cannot pay became redundant. Instead, it was suggested that willingness to pay should be considered and to ask whether the users are aware of the costs for achieving good WWTP performance. Willingness to pay is linked to the level of information among users regarding necessary costs (Birol and Das, 2012; Vásquez et al., 2009) and was suggested to be included in the tool. Affordability for customers is highlighted as an important sustainability issue in several studies (Balkema et al., 2002; Singhirunnusorn and Stenstrom, 2009), and is likely to affect how many people are connected to the drinking water and wastewater treatment systems. Differentiated tariffs, a good level of knowledge of the customers' payment capacity, good communication, and raising awareness among the general public about the benefits of a WWTS, are all interlinked. A study dealing with customers' willingness to pay is thus likely to be dependent on several factors in the assessment tool.

4.2.4. Institutional dimension

Excluding indicator I2 Institutional capacity (higher level) from the assessment was suggested, since the managers do not have control over improving and motivating external stakeholders to carry out their roles. It was stated that it would take a great deal of time and effort

to achieve this. On the other hand, the assessment as it is currently being implemented, could help to communicate a lack of institutional capacity at higher levels to induce those concerned to search for strategies to achieve sustainability. In our previous study on sustainability indicators in the context of low and lower-middle-income countries (Cossio et al., 2020), the institutional dimension was highlighted as being of prime importance by local technical and social experts. Indeed, it is difficult to expect that a WWTS will function well without local and institutional support.

4.3. Application of the assessment tool in practice

4.3.1. How can the assessment results be used?

The manager of WWTS-1 stated that "the sustainability assessment tool was very interesting as it can provide us with a final score for the overall sustainability level of the system". On the other hand, the process used to perform the assessment is expected to be even more important than the results as it guides the assessor (s) through the targets needed to achieve sustainability. The assessment results can be used to understand the system and at the same time used to communicate performance and work at the utility, both to the general public and to other institutions that are expected to provide support or to monitor the utility's performance. Repeating the assessment over time is also a means of following up and communicating progress regarding improvements.

The results on the factor level (see Appendix C) provide the assessors with more detailed information about the steps that need to be taken to improve identified weaknesses. Certain actions could potentially be implemented in the short term, e.g. increasing the monitoring frequency or developing a manual of procedures for the O&M of specific technologies (assuming there are short-term resources available). Nonetheless, many of the actions may require a longer timeframe if they are to be achieved. The formulation and implementation of long-term plans for improving the sustainability level typically requires action to be taken in all the dimensions. A wider application of the EVAS tool in a region or in a municipality, could also help authorities to prioritize actions at these levels.

4.3.2. Who should perform the assessment?

Where more than one institution is responsible for the management of the WWTS, they should all participate in the assessment to obtain more accurate answers. In Case study 1, the municipality is responsible for financial management, and the manager was unable to provide complete reassurance that long-term maintenance plans could be implemented for all the treatment units as it would require investment in the infrastructure. The manager was therefore not in a position to take action to improve the situation, as responsibility would rest with external parties. In these cases, the tool and the assessment could function as a means of communicating the difficulties encountered by the WWTS on its path towards sustainability.

4.3.3. How should the assessment be carried out?

We suggest using this assessment within a broader participatory assessment framework (Fig. 4). The suggested framework includes four main stages:

i. *Identification of assessor or group of assessors.* The assessor should preferably be the manager and the staff in charge of the main activities in the WWTS, although the participation from local stakeholders and external experts involved in the WWTS management might also be needed. Assessors should be able to provide information for the assessment and input on the weighting of the variables of the tool (i.e. dimensions, indicators, sub-indicators and factors).

ii. *Assessment of the current sustainability status of the WWTS using the EVAS tool.* If necessary, weights can be modified at this stage, preferably by involving stakeholders. The weighting may be useful to
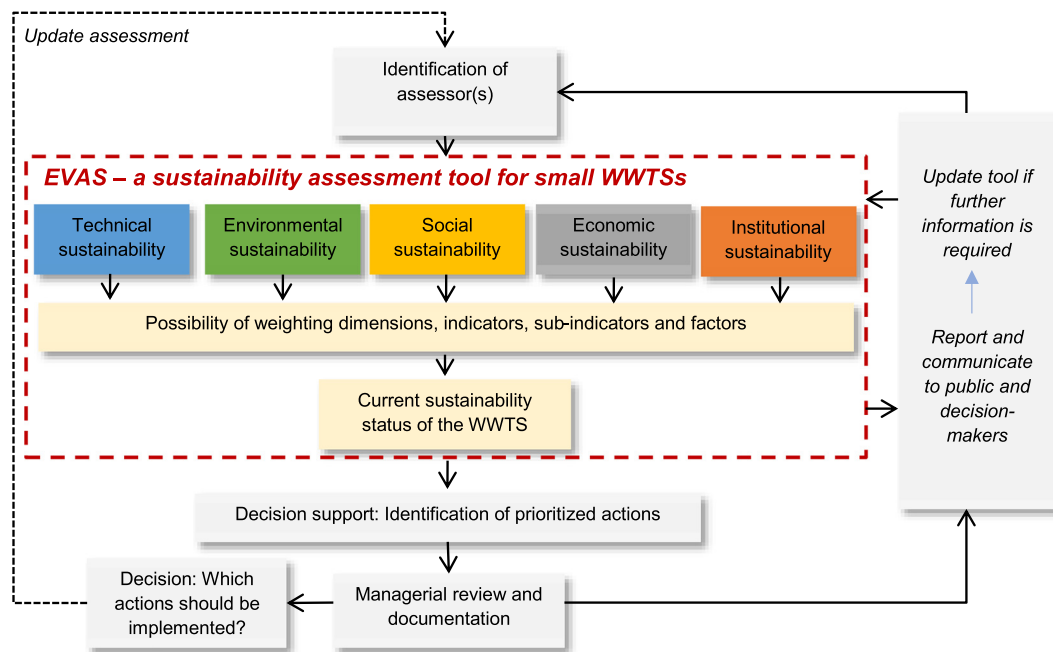
Fig. 4. Outline of the proposed sustainability assessment framework adapted from Rosén et al. (2015). The extent of the EVAS tool is indicated by the dashed red line. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

prioritize actions in the resulting to-do list or to discuss the different perspectives among the stakeholders involved in the assessment.

iii. *Revision and communication of the results from the assessment by managers of the WWTS.* Identification of aspects in the WWTS with a low level of sustainability support the prioritization of actions that can be implemented. To facilitate quality assurance, the assessment must be documented fully and preferably reviewed before being communicated. Effective communication of the results to the general public and decision-makers can motivate their support in the process of enhancing the sustainability of the systems.

iv. *Iteration.* The suggested framework indicates an iterative working process as the assessment may require additional data collection or it can be updated as new data becomes available. The assessment can be updated and followed up over time to record improvements in the sustainability of the WWTS.

4.4. The complexity of sustainable small WWTS in low and lower-middle income countries

Treating wastewater in a low and lower-middle income country is a service that differs from most other community services, such as water and electricity, and presents additional challenges. Wastewater treatment generally benefits or affects people living downstream of the town depending on the efficiency of the WWTS, whereas the burden of operating and financing the WWTP rests with those living in the town. The benefit of wastewater treatment is only partly apparent, because most of the contaminants are invisible, unless of course the water recipient has a low flow, in which case the contamination is evident. The main benefit to the downstream recipients is also invisible and can only be measured using advanced methods. It may also take time before improvements become apparent. On the other hand, every failure or local nuisance (e.g. smell) caused by the local WWTP will be noted immediately, especially when in a sceptical community. Local benefits, such as reuse of treated wastewater and sludge

and the possibility of employment, may be recognized and are important to highlight. In a context where wastewater treatment is a new phenomenon, it could be a challenge to find competent staff for the WWTP and the community may not fully understand how their use of the service has an impact on the sustainable development of their town. It may also be difficult for local, regional and national regulators to understand how much support and regulation is needed to initiate efficient wastewater treatment. As wastewater treatment demands considerable financial investment that generates benefits over an extended period of time, it may be better to initially introduce a simple yet stable treatment process. This could give rise to important improvements and local benefits and provides the possibility of improving treatment over time, rather than expecting an immediate, large-scale investment in technology that cannot be handled correctly or be sustained. The EVAS tool aims to support managers in the complex decision-making process as a means of improving current small wastewater treatment services in low and lower-middle income countries sustainably.

5. Conclusions

In summary, the main conclusions from this study are:

- The EVAS tool can provide managers of small WWTSs in low and lower-middle income countries with the means to identify weaknesses in the management of their systems, and to better understand the needs of the WWTS in their endeavour to achieve improved performance and sustainability.
- The sustainability level of WWTS-1 was reported to be medium. Suggested prioritized strategies to bring about further improvements include increasing the monitoring of effluents, improving the sewer network, and following up low levels of removal efficiency as well as the affordability for the wastewater treatment system.
- The sustainability level of WWTS-2 is low. Suggested prioritized strategies include increasing the monitoring of effluents, improving the

sewer network, and following up on low levels of removal efficiency. However, these must be accompanied by efforts in all sustainability dimensions, including improving the organization of the utility and communicating more effectively with users.

- For WWTS-1 where the function as well as the environmental performance was better, also the social and institutional dimensions scored higher than for WWTS-2, indicating an interconnection between dimensions and the need to take a holistic view.
- The sewer systems of both WWTSs scored low, and long-term plans to improve the status of the sewer system were not available, potentially causing increased future problems with the sewer systems, increasing bypass of wastewater and hydraulic overloading the WWTP.
- The EVAS tool may be used to involve local stakeholders in the assessment and to communicate with decision-makers and external stakeholders to receive better support for identified strategies in order to raise the sustainability level of small WWTSs.
- The EVAS tool is also useful for public or regulatory authorities, as they can apply the tool on WWTSs in their region, compare the status of several WWTPs, and based on these results formulate support and investment strategies.

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CRediT authorship contribution statement

Claudia Cossio: Conceptualization, Methodology, Software, Investigation, Writing - original draft, Writing - review & editing, Visualization. **Jennifer R. McConville:** Conceptualization, Methodology, Writing - review & editing, Supervision. **Ann Mattsson:** Methodology, Writing - review & editing. **Alvaro Mercado:** Investigation, Writing - review & editing, Project administration. **Jenny Norrman:** Conceptualization, Methodology, Software, Formal analysis, Writing - review & editing, Supervision, Project administration.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Equations and calculations in the EVAS tool

Each factor (f) in the EVAS tool is a assigned a score (S_f) by the user between 0 and 4 according to the traffic light scale, and a weight (W_f) according to the importance of the factor. Standard weights in the EVAS tool are 1 or 2, but any number can be set by the user if motivated: the higher the number the higher importance of the factor (sub-indicator, indicator, or dimension). The normalised weight ($w_{f,si}$) of each factor under each sub-indicator (si) is calculated as:

$$w_{f,si} = \frac{W_{f,si}}{\sum_{f=1}^{F} W_{f,si}} \tag{A-1}$$

The sub-indicator scores (S_{si}) are then calculated as a weighted sum:

$$S_{si} = \sum_{f=1}^{F} w_{f,si} S_f \tag{A-2}$$

Each sub-indicator is also given a weight (W_{si}) according to the relative importance of the sub-indicator and a normalised weight ($w_{si,i}$) is calculated for each sub-indicator included in an indicator (i) as:

$$w_{si,i} = \frac{W_{si,i}}{\sum_{si=1}^{SI} W_{si,i}} \tag{A-3}$$

The indicator scores (S_i) are calculated as:

$$S_i = \sum_{si=1}^{SI} w_{si,i} S_{si} \tag{A-4}$$

According to the same principle, each indicator is given a weight (W_i), and the normalised weight ($w_{i,d}$) of each indicator under each dimension (d) is calculated as:

$$w_{i,d} = \frac{W_{i,d}}{\sum_{i=1}^{I} W_{i,d}} \tag{A-5}$$

The dimension scores (S_d) are calculated as:

$$S_d = \sum_{i=1}^{I} w_{i,d} S_i \tag{A-6}$$

Each of the five dimensions is given a weight (W_d), and the normalised weight (w_d) of each dimension is calculated as:

$$w_d = \frac{W_d}{\sum_{d=1}^{D} W_d} \qquad (A-7)$$

Finally, the overall score (S_o) of the EVAS tool is calculated as:

$$S_o = \sum_{d=1}^{D} w_d S_D \qquad (A-8)$$

Further, in the EVAS tool, there are two types of logical functions related to the calculations of the scores included, listed below.
- If there is no monitoring at all regarding any sub-indicator relating to factors T1-I, E1-II, E2-I, and E3-I, the resulting score of that sub-indicator becomes 0.
- If targets are reached for a sub-indicator on a medium or high level, the last factor of that sub-indicator relating to implementation of long-term plans is regarded as not relevant (n.r.) and left out of the assessment. This relates to indicators T1, T3, T4, E1, E2, E3, S1, S2, S3, S4, EC2, I3, I5.

Appendix B. Overview of the content of the sustainability assessment tool

Table B1
List of sustainability dimensions, indicators, sub-indicators and factors, and their respective weightings (w.).

Technical dimension				DIM. W.:	1
Technical indicators	Ind. w.	Sub-indicators	S-ind. w.	Factors	Factor w.
T1. Removal efficiency (RE)	1	T1a. BOD	1	T1-I. Monitoring RE	1
		T1b. TSS	1	T1-II. Removal efficiency	2
		T1c. TN	1	T1-III. Long-term plan RE	1
		T1d. TP	1		
		T1e. FC	1		
T2. Operation and maintenance (O&M)	1	T2a. Pre-treatment	1	T2-I. Manuals	1
		T2b. Primary treatment	1	T2-II. Short-term O&M	1
		T2c. Secondary treatment	1	T2-III. Long-term maintenance	1
		T2d. Tertiary treatment	1		
		T2e. Disinfection	1		
T3. Sewer network functionality (SEW)	1	–	–	T3-I. Coverage	2
				T3-II. Design	2
				T3-III. Breakdown	1
				T3-IV. Hydraulic loading	2
				T3-V. Clogging	1
				T3-VI. Long-term plan SEW	1
T4. Reliability of the WWTP	1	–	–	T4-I. Design of the WWTP	2
				T4-II. Breakdown	1
				T4-III. Hydraulic loading	2
				T4-IV. Organic loading	1
				T4-V. Long-term plan WWTP	1

Environmental dimension				DIM. W.:	1
Environmental indicators	Ind. w.	Sub-indicators	S-ind. w.	Factors	Factor w.
E1. Potential safe reuse (SR)	1	E1a.Water	1	E1-I. Reuse practice	1
		E1b. Sludge	1	E1-II. Monitoring SR	1
				E1-III. Safe reuse limits	2
				E1-IV. Long-term plan SR	1
E2. Eutrophication potential (EP)	1	E2a. TN	1	E2-I. Monitoring EP	1
		E2b. TP	1	E2-II. Eutrophication potential	2
				E2-III. Long-term plan EP	1
E3. Effluent quality (EQ)	1	E3a. BOD	1	E3-I. Monitoring EQ	1
		E3b. TSS	1	E3-II. Discharge limits	2
				E3-III. Long-term plan EQ	1
E4. Energy	1	–	–	E4-I. Energy-saving programme E4-II. Renewable energy	1
					1
E5. Global warming potential	1	–	–	E5-III. Emissions reduction	–

Social dimension				DIM. W.:	1
Social indicators	Ind. w.	Sub-indicators	S-ind. w.	Factors	Factor w.
S1. Public health risk (PH)	1	–	–	S1-I. Exposure	2
				S1-II. Claims	1
				S1-III. Long-term plan PH	1
S2. Public awareness (PA)	1	–	–	S2-I. Ecological concerns	1
				S2-II: Public health concerns	1
				S2-III. Use of services	1

Table B1 (*continued*)

Social dimension				DIM. W.:	1
Social indicators	Ind. w.	Sub-indicators	S-ind. w.	Factors	Factor w.
				S2-IV. Long-term plan PA	1
S3. Aesthetics (AES)	1	S3a. Smell	1	S3-I. Perception	1
		S3b. Noise	1	S3-II. Nuisance level	2
		S3c. Visual impact	1	S3-III. Action plan AES	1
S4. Public acceptance (PACC)	1	–	–	S4-I. Location of WWTP	1
				S4-II. Reuse practice	1
				S4-III. Long-term plan PACC	1

Economic dimension				DIM. W.:	1
Economic indicators	Ind. w.	Sub-indicators	S-ind. w.	Factors	Factor w.
EC1. Tariffs	1	–	–	EC1-I. Tariff structure	1
				EC1-II. Documentation	1
				EC1-III. Follow-up	1
EC2. Operation and maintenance costs	1	–	–	EC2-I. Economic requirements	1
				EC2-II. Long-term investment	1
				EC2-III. Long-term plan O&M	1
EC3. Affordability (AF)	1	–	–	EC3-I. Payment of tariffs	1
				EC3-II. Payment capacity	1
				EC3-III. Strategy AF	1

Institutional dimension				DIM. W.:	1
Institutional indicators	Ind. w.	Sub-indicators	S-ind. w.	Factors	Factor w.
I1. Institutional capacity (utility)	1	–	–	I1-I. Roles and responsibility	1
				I1-II. Procedures	1
				I1-III. Goals of the organization	1
				I1-IV. Long-term goals	1
I2. Institutional capacity (higher level)	1	I2a. Municipal	1	I2-I. Clear roles	1
		I2b. Regional	1	I2-II. External support	1
		I2c. National	1		
I3. Staff requirements (SR)	1	I3a. Operator	1	I3-I. Availability	1
		I3b. Engineer	1	I3-II. Level of expertise	1
		I3c. Communicator	1	I3-III. Long-term plan SR	
		I3d. Accountant	1		
		I3e. Manager	1		
I4. Employee satisfaction	1	–	–	I4-I. Working conditions	1
				I4-II. Salary level	1
I5. Communication	1	–	–	I5-I. Use of services	1
				I5-II. Wastewater utility	1
				I5-III. Warnings regarding exposure risks	1

Appendix C. Detailed results from the case studies

Table C1
Detailed results from the sustainability assessment for Case study 1. Factors that scored 0, 1 and 2 are presented in order, with lower scores and higher weightings first.

CODES	SCORE	FACTOR WEIGHTING	INDICATOR SUB-INDICATOR	FACTOR
TECHNICAL DIMENSION				
T3-II	1	2		T3-II Design
T3-IV	1	2		T3-IV Hydraulic loading
T3-III	1	1	**T3. Sewer network functionality**	T3-III Breakdown
T3-V	1	1		T3-V Clogging
T3-VI	1	1		T3-VI Long-term plan SEW
T1b-II	2	2	**T1. Removal efficiency**	T1-II. Removal efficiency
T1e-II	2	2		T1-II. Removal efficiency
T2a-III	2	1	**T2. Operation and maintenance**	
T2b-III	2	1	T2a. Pre-treatment T2b. Primary treatment	T2-III Long-term maintenance
T2c-III	2	1	T2c. Secondary treatment	
ENVIRONMENTAL DIMENSION				
E1b-II	1	1	**E1. Potential safe reuse** E1b. Sludge	E1-II Monitoring SR
E4-I	1	1	**E4. Energy**	E4-I Energy-saving programme
E4-II	1	1		E4-II Renewable energy
E5-I	1	-	**E5. Global warming potential**	E5-I Emissions reduction
SOCIAL DIMENSION				
S1-II	2	1	**S1. Public health risk**	S1-II Claims
ECONOMIC DIMENSION				
EC1-III	1	1	**EC1. Tariffs**	EC1-III Follow-up
EC3-II	2	1	**EC3. Affordability**	EC3-II Payment capacity
EC3-III	2	1		EC3-III Strategy AF
INSTITUTIONAL DIMENSION				
I2b-I	1	1	**I2. Institutional capacity (higher level)** I2b. Regional	I2-I Clear roles
I2b-II	1	1	**I2. Institutional capacity (higher level)** I2b. Regional	
I2c-II	1	1	I2c. National	I2-II External support
I2a-II	2	1	**I2. Institutional capacity (higher level)** I2a. Municipal	
I3c-I	2	1	**I3. Staff requirements** I3c. Communicator	
I3d-I	2	1	I3d. Accountant	I3-I Availability
I3e-I	2	1	I3e. Manager	
I5-II	2	1	**I5. Communication**	I5-II Wastewater utility performance

Table C2
Detailed results from the sustainability assessment for Case study 2, factors that scored 0, 1 and 2 are presented in order, with lower scores and higher weightings first.

CODE	SCORE	FACTOR WEIGHTING	INDICATOR SUB-INDICATOR	FACTOR
TECHNICAL DIMENSION				
T1a-II	1	2	**T1. Removal efficiency**	
T1c-II	1	2	T1a. BOD	
T1d-II	1	2	T1c. TP	T1-II. Removal efficiency
T1e-II	1	2	T1d. TN T1e. FC	
T3-II	1	2	**T3. Sewer network functionality**	T3.-II Design
T3-IV	1	2		T3-IV. Hydraulic loading
T1a-I	1	1	**T1. Removal efficiency**	
T1b-I	1	1	T1a. BOD	
T1c-I	1	1	T1b. TSS T1c. TP	T1-I. Monitoring RE
T1d-I	1	1	T1d. TN	
T1e-I	1	1	T1e. FC	
T2a-I	1	1	**T2. Operation and maintenance**	
T2b-I	1	1	T2a. Pre-treatment T2b. Primary treatment	
T2c-I	1	1	T2c. Secondary treatment	T2-I. Manuals
T2d-I	1	1	T2d. Tertiary treatment	
T2b-III	1	1	**T2. Operation and maintenance**	
T2c-III	1	1	T2b. Primary treatment T2c. Secondary treatment	T2-III. Long-term maintenance
T2d-III	1	1	T2d. Tertiary treatment	
T3-V	1	1	**T3. Sewer network functionality**	T3-V. Clogging
T3-VI	1	1		T3-VI. Long-term plan SEW
T3-I	2	2	**T3. Sewer network functionality**	T3-I. Coverage
T4-I	2	2	**T4. Reliability of the WWTP**	T4-I. Design of the WWTP
T4-III	2	2		T4-III. Hydraulic loading
T1a-III	2	1	**T1. Removal efficiency**	
T1c-III	2	1	T1a. BOD T1c. TP	T1-III. Long-term plan RE
T1d-III	2	1	T1d. TN	
T1e-III	2	1	T1e. FC	
T2a-II	2	1	**T2. Operation and maintenance**	
T2b-II	2	1	T2a. Pre-treatment T2b. Primary treatment	T2-II. Short-term O&M
T2c-II	2	1	T2c. Secondary treatment	
T2d-II	2	1	T2d. Tertiary treatment	
T2a-III	2	1	**T2. Operation and maintenance** T2a. Pre-treatment	T2-III. Long-term maintenance
ENVIRONMENTAL DIMENSION				
E1b-III	0	2	**E1. Potential safe reuse** E1b. Sludge	E1-III. Safe reuse limits
E1a-III	1	2	**E1. Potential safe reuse** E1a. Water	E1-III. Safe reuse limits
E2a-II	1	2	**E2. Eutrophication potential**	
E2b-II	1	2	E2a. TN E2b. TP	E2-II. Discharge limits
E3a-II	1	2	**E3. Effluent quality** E3a. BOD	E3-II. Discharge limits
E1a-II	1	1	**E1. Potential safe reuse** E1a. Water	E1-II. Monitoring SR
E1b-II	1	1	E1b. Sludge	

Table C2 *(continued)*

E1a-IV	1	1	**E1. Potential safe reuse** E1a. Water E1b. Sludge	E1-IV. Long-term plan SR
E1b-IV	1	1		
E2a-I	1	1	**E2. Eutrophication potential** E2a. TN E2b. TP	E2-I. Monitoring EP
E2b-I	1	1		
E2a-III	1	1	**E2. Eutrophication potential** E2a. TN E2b. TP	E2-III. Long-term plan EP
E2b-III	1	1		
E3a-I	1	1	**E3. Effluent quality** E3a. BOD E3b. TSS	E3-I. Monitoring QE
E3b-I	1	1		
E4-I	1	1	**E4. Energy**	E4-I. Energy saving
E4-II	1	1	**E4. Energy**	E4-II. Renewable energy
E5-I	1	-	**E5. Global warming potential**	E5-I. Emissions reduction
E3b-II	2	2	**E3. Effluent quality** E3b. TSS	E3-II. Discharge limits
E1a-I	2	1	**E1. Potential safe reuse** E1a.Water	E1-I. Reuse practice
E3a-III	2	1	**E3. Effluent quality** E3a. BOD E3b. TSS	E3-III. Long-term plan QE
E3b-III	2	1		
SOCIAL DIMENSION				
S1-I	1	2		S1-I. Exposure
S1-II	1	1	**S1. Public health risk**	S1-II. Claims
S1-III	1	1		S1-III. Long-term plan PH
S2-I	1	1		S2-I. Ecological concerns
S2-III	1	1	**S2. Public awareness**	S2-III. Use of services
S2-IV	1	1		S2-IV. Long-term plan PA
S3.a-III	1	1	**S3. Aesthetics** S3a. Smell	S3-III. Long-term plan AES
S4-II	1	1	**S4. Public acceptance**	S4-II. Reuse practice
S4-III	1	1	**S4. Public acceptance**	S4-III. Long-term plan PACC
S3a-II	2	2	**S3. Aesthetics** S3a. Smell	S3-II. Nuisance level
S3a-I	2	1	**S3. Aesthetics** S3a. Smell S3b. Noise S3c. Visual impact	S3-I. Perception
S3b-I	2	1		S3-I. Perception
S3c-I	2	1		S3-I. Perception
S4-I	2	1	**S4. Public acceptance**	S4-I. Location of the WWTP
ECONOMIC DIMENSION				
EC3-II	0	1	**EC3. Affordability**	EC3-II. Payment capacity
EC3-III	0	1		EC3-III. Strategy AF
EC1-III	1	1	**EC1. Tariffs**	EC1-III. Follow-up
EC2-I	1	1	**EC2. Operation and maintenance costs**	EC2-I. Economic requirements
EC2-II	2	1	**EC2. Operation and maintenance costs**	EC2-II. Long-term investment
EC2-III	2	1		EC2-III. Long-term plan OM

Table C2 (continued)

INSTITUTIONAL DIMENSION				
I1-III	1	1	**I1. Institutional capacity (utility)**	I1-III. Goals of the organization
I1-IV	1	1		I1-IV. Long-term goals
I2a-I	1	1	**I2. Institutional capacity (higher level)** I2a. Municipal I2c. National	I2-I. Clear roles
I2c-I	1	1		
I2a-II	1	1		I2-II. External support
I2c-II	1	1		
I3c-I	1	1	**I3. Staff requirements** I3c. Communicator	I3-I. Availability
I3c-II	1	1		I3-II. Level of expertise
I3a-III	1	1	**I3. Staff requirements** I3a. Operator I3b. Engineer I3c. Communicator I3d. Accountant I3e. Manager	I3-III. Long-term plan SR
I3b-III	1	1		
I3c-III	1	1		
I3d-III	1	1		
I3e-III	1	1		
I5-II	1	1	**I5. Communication**	I5-II. Wastewater utility performance.
I5-III	1	1		I5-III. Warning regarding risk exposure
I1-II	2	1	**I1. Institutional capacity (utility)**	I1-II. Procedures
I3b-I	2	1	**I3. Staff requirements** I3b. Engineer I3d. Accountant I3e. Manager	I3-I. Availability
I3d-I	2	1		
I3e-I	2	1		
I3a-II	2	1	**I3. Staff requirements** I3a. Operator I3e. Manager	I3-II. Level of expertise
I3e-II	2	1		
I4-I	2	1	**I4. Employee satisfaction**	I4-I. Working conditions
I4-II	2	1		I4-II. Salary level
I5-I	2	1	**I5. Communication**	I5-I. Use of sewer network services

Appendix D. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.scitotenv.2020.140938.

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